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# Physical Models of Off-Road Vehicles Moving on Loose Soils

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**Abstract** - This video illustrates physically-based particle simulations of various off-road vehicles moving on deformable soils, leaving tyre traces, spinning, skidding and even sinking.

**Key Words** - Physical Modeling, Dynamic Simulation, Off-Road Vehicle, Loose Soil.

## 1. Introduction

Manufactured soils have simple dynamical behaviour, such as quite-rigid behaviours. Then, we can model the system soil - vehicle as an open-looped system taking into account only the action of the soil onto the vehicle. At the opposite, natural environments present more complex dynamical behaviors : rolling stones, non neglectible deformations, compressions, avalanches, collapses... The geometry of the terrain can highly modify by the vehicle itself during its displacements. And simultaneously, the behavior of the vehicle becomes also more complex : sliding, skidding, slipping ... The modelling of this situation requires the use of closed-loop systems, in which the soil physically acts on the vehicle, modifying its motion, and at the same time, the vehicle physically acts on the soil, causing deformations and transformations.

Deformable soils, such as loose soils cannot be modelled by solid physics and they require the use of punctual mass decomposition and mass-mass interactions.

These are the basis of the modeller-simulator called CORDIS - ANIMA we used, in which every kind of physical object is modelled by a set of punctual masses in physical interaction [2] [3]. The interactions can be linear elasticities and linear viscosities as well as non linear elastic bumper, cohesion interaction, dry friction, and plastic interaction, used in these works.

## 2. Deformable Soil Models

With this physically-based particle modeler, we have developed physical models of rigid soils with dynamical dry friction, and deformable soils composed of rigid parts such as a substratum with rigid stones able to roll on it, under the action of the vehicle [1] [4] [5].

In [7], we have been interested on the modelling of loose soils such as sand layers. The first stage has been to model the sand itself and more generally granular material in different conditions ; dry sand, moist muds. The model is composed of a set of punctual masses, all linked by visco-elastic buffer interactions and poured on a rugged medium. As it can be seen on the video, with this model, we obtained the major phenomena which characterize the dynamical behaviour of granular materials : different kinds of piling, surfacic avalanches, collapses, arching and so on.

To model loose soils, the second stage, is to adapt this general model of granular material to the specificity of soils. Instead of the lot of phenomena occurring in granular materials such as large avalanches and collapses, what we need in soil modelling is mainly compression, shear and plastic deformations. Then, we designed, from the first model of granular materials, an optimized model for the soil, which has a constant layer-based topology [9] [10].

## 3. Modeling Plasticity

Then, plasticity must be modelled in another way : Not as an emergent phenomena due to the sum of microscopic collisions but as a complex interaction component producing directly plasticity. The so called plastic interaction is elastic for small deformations; after a threshold, called "plastic threshold", it remains elastic but with another rest deformation, and so on ...

Then, a loose soil can be modelled by a set of masses linked by three plastic interactions : a vertical interaction to model the compression resistance; an horizontal one to model the shear; a mass-mass interaction to model the cohesion forces in the soil surface. By adjusting the rest position of these masses, we draw the geometrical profile of the rigid substratum [9] [10]. Because plastic interaction has successive irreversible thresholds, we model irreversible complex compressions and shears with successive stages of compression or shear, according to the history of the system. The video illustrates these phenomena.

## 4. Physically-Based Models of Vehicles

Our vehicles must move on every kind of soils: rigid, rigid and mobile, but also deformable and loose soils. We



cannot use other discretisation elements than punctual masses. We have used also the CORDIS - ANIMA modelor-simulator to model every kind of vehicles, having rigid parts such as chassis or deformable parts, such as wheels with tires [6].

To be always physically consistant with the physical representation system used for soils and chassis, we have created an elementary Cordis-Anima actuator which satisfies to physical action - reaction principle. With this physically consistant actuator, we motorized several part of the vehicle : the wheels, the automatic steering and the peristaltic motion of the chassis.

## 5. Simulation Results and Video Contents

The video shows a set of dynamically - based simulations of different kinds of vehicles, with different kinds of motorization, moving on loose soils.

It contains successively :

- Vehicles moving on rigid soils [1]:

The rovers have no internal motors. But there is a dry friction between the wheels and the soil.

- Vehicles moving on mobile soils [1]:

Rocks are mobile and there is dry friction between wheels and pebbles and pebbles and substratum. The video illustatres the action from the rover to the rocks and the action from the rocks to the rover.

- Experiments on the simulation of granular material [7]:

Thanks to the dry friction between each mass and the ground for causing the piling, the avalanches and the internal collapses.

- A rocky-type rover moving on a loose soil [6] [9] [10]:

The interactions between the rover and the soil are visible. The rover marks the soil and the soil modifies the motion of the rover. The video illustrates the progression of the compression after the crossing of the first wheel, the second and the third and the simultaneous deformations of the soil and of the wheel.

- A 2D-wheels motorized rover :

The rover skids when it tries to climb the slope. But the soil is a loose soil, so the wheels pack the soil and the grip is recovered.

- A rover with two tracked bogies [6] [9] [10] :

With this rover, we can see the behavior of a rocky type rover. The axis of the front bogie can be moved back or forth. So it is possible to study the influence of mass distribution on the rover's capacities.

- A rover with dynamically controlled peristaltic motion :

The video shows the influence of the peristaltic motion on the crossing over of the vehicle moving on plastic natural profiled terrain [6] [9] [10].

- 3D simulation with rendering [6] [9] [10] :

To perform such simulations, we have created soil models. Then, path planning was performed. The path is obtained by physical modeling. Once the control points' position are obtained, the simulation of the rover can be performes. The first simulation shows a rover with its steering which

marks a loose soil. The second simulation shows a rover moving on this kind of soil with rigid pebbles bore on it. On the third simulation, the rover cannot cross over the slope. The wheels are sliding and the vehicle stops.

- Force feed back real time driving [8]:

The last sequence shows a real time simulation. This simulation is done with a two dimensionnal vehicle control by a force feedback gestural interface. This interface reads positions and return forces with a 1KHz sampli,g rate. This rate allows to realistically feel hard collisions and vehicle behavior.

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